PROJECTION LENS SYSTEM

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a projection lens system for a projection device, and more particularly to a compact projection lens system that is capable of correcting a color aberration.

Description of the Related Art

Recently, there has been rapidly spread a projection-type device for magnificently projecting a small-size image using a projection lens as a request for a large-scale screen and a high quality image in a display device increases. The projection-type device is largely classified into a front projection system and a rear projection system depending on a direction in which a picture is projected onto a screen. The rear projection system has been more highlighted on an advantage in that it can display a relatively bright picture even at a place where a peripheral environment thereof is bright. A typical rear projection device includes a projection television (TV). The projection TV does mainly use a cathode ray tube (CRT) and a liquid crystal display, etc. as a light source for implementing a small picture. A small picture re-expressed on the CRT or the liquid crystal panel is enlarged by the projection lens and

thereafter is projected onto the rear surface of the screen in such a manner to be displayed as a large picture.

Referring to Fig. 1A and Fig. 1B, there are shown a front internal structure and a side internal structure of a projection TV using a light source as the conventional CRT, respectively. The projection TV includes a CRT 2 for displaying a picture corresponding to image signals, a projection optical system 4 for magnificently projecting the picture displayed on the CRT 2, a reflecting mirror 6 for reflecting the picture projected from the projection lens system 4 into a screen 8, and a screen 8 for displaying the picture projected magnificently by the projection lens system 4. As shown in Fig. 1A, the CRT 2 consists of red, green and blue CRTs 2R, 2G and 2B to display each of red, green and blue color pixel. The projection lens system 4 consists of red, green and blue projection lens systems 4R, 4G and 4B arranged at an outlet of each red, green and blue CRT 2R, 2G and 2B to magnificently project a picture from each red, green and blue CRT 2R, 2G and 2B. The reflecting mirror 6 allows the screen 8 to display a large color picture by reflecting a picture projected magnificently by means of the red, green and blue projection lens systems 4R, 4G and 4B to be imaged on the screen 8. In this case, the projection lens system 4 requires to assure a performance capable of resolving scanning lines on the CRT through corrections of a spherical aberration, an astigmatism, a distortion and a color aberration in order to realize a high definition. To this end, each of the red, green and blue projection lens systems 4R, 4G and 4B consists of a plurality of plastic

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lenses` and a glass lens.

The basic configuration of the projection lens system is described in detail in U.S. Patent Nos. 4,300,817, 4,384,081, 4,526,442 and 4,697,892. Also, U.S. Patent No. 4,685,774 discloses a projection lens system for increasing a variation of refractive power in an aspheric surface in the optical axis and the margin to correct an aberration generated along with the increasing of field view angle. Further, U.S. Patent No. 4,776,581 teaches a projection lens system capable of increasing the field view angle and being compact. However, the projection lens system disclosed in U.S. Patent Nos. 4,300,817, 4,384,081, 4,526,442, 4,697,892, 4,685,774 and 4,776,581 can not obtain a good performance in the brightness and so on, due to F/# of about 1.0. In other words, the projection lens system must have the F/# of below 1.0. However, the projection lens system disclosed in the above U.S. Patents can not obtain the F/# of below 1.0 by the proposed lens configuration and the dispersion of refractive power.

Also, U.S. Patent No. 4,963,007 discloses an axial chromatic correction as an aberration correction art. conventionally, the axial chromatic correction is defined as the following equation:

$$K/\nu = K_1 / (\nu_1 + K_2)/ \nu_2 \ {-} \ (1)$$

Wherein, $= K_1$ and K_2 are refractive powers of lens elements L1 and L2, and ν_1 and ν_2 are values of dispersion

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(1/Abbe's number) for the lens elements L1 and L2. ν_1 and ν_2 can correct the axial chromatic aberration because having an infinite value when the value of K/ν in the equation (1) is "0". The projection lens system proposed

5   in the U.S. Patent No. 4,963,007 distributes appropriately the refractive power and combines lenses having the dispersion value different from each other so as to correct the axial chromatic aberration. Also, a projection lens system disclosed in U.S. Patent No.

10 5,272,540 teaches a configuration of cemented doublet for correcting the axial chromatic aberration. These projection lens systems disclosed in the above U.S. Patents are adapted to correct the axial chromatic aberration because lenses is split according to the

15 dispersion of refractive power or the cemented doublet is used for the projection lens system. However, these projection lens systems allow to cost up due to the increasing of unnecessary lenses. The projection lens system described in the above U.S. Patent No. 4,963,007

20 combines glass lenses of Flint series and Crown series or plastic lenses of polystyrene and acrylic series so as to correct the axial chromatic aberration. Also, the projection lens system disclosed in the above U.S. Patent No. 5,272,540 employs a cemented doublet, which lenses of

25 different Abbe's number is banded, so as to correct the optical axial chromatic aberration. The configuration of the projection lens system disclosed in the above U.S. Patent No. 5,272,540 is shown in Fig. 2.

30 The projection lens system of Fig. 2 includes first and second lenses 10 and 12 having a weak refractive power, a

third lens 14 responsible for a major positive refractive power of the projection lens system, a fourth lens 16 having a weak positive refractive power, and a fifth lens 18 having a strong refractive power. The first lens 10 plays a role to correct a spherical aberration while the second lens 12 plays a role to correct a comma aberration and astigmatism. These first and second lenses 10 and 12 are made from a plastic material. The fourth and fifth lenses 16 and 18 are made from a plastic material, which plays a role to correct astigmatism. The third lens 14 consists of a doublet made from a glass to correct a color aberration. In other words, the third lens 14 corrects a color aberration using a combination of lenses having a positive refractive power with lenses having a negative refractive power.

As described above, the projection lens system disclosed in U.S. patent no. 5,272,540 consists of a doublet and a plurality of lenses so as to correct a color aberration and various optical aberrations. Because the projection system of U.S. patent no. 5,272,540 has a number of lenses, it has a difficult in making a small dimension construction and causes a rise in a manufacturing cost. This requires a projection lens system capable of realizing a high resolution and a high brightness with reducing the number of lenses.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to

provide a projection lens system capable of realizing a high definition and a high brightness by correcting a chromatic aberration and designing in low f number (F/#).

In order to achieve these and other objects of the invention, a projection lens system according to an aspect of the present invention includes a plurality of refractive lenses and at least one diffractive optical element formed on at least one among the surfaces of the refractive lenses.

A projection lens system according to another aspect of the present invention includes a plurality of refractive lenses and at least one diffractive optical element formed on at least one among the faces of the refractive lenses to correct aberrations at an axis and the outside of the axis.

A projection lens system according to still another aspect of the present invention includes a first lens for correcting an aberration generated by a variation of height from a light axis, the first lens having at least one surface formed with diffractive optical element thereon; a second lens for refracting lights passed through the first lens; and a third lens for correcting a field curvature and an astigmatism of the lights passed through the second lens.

A projection lens system according to still another aspect of the present invention includes: a first lens having a positive refractive power at the center thereof and a

negative refractive power at the peripheral thereof; a second lens having a relatively large positive refractive power; a third lens having a positive refractive power; a fourth lens having a negative refractive power; and at least one diffractive optical element formed on at least one among the surfaces of the lenses.

A projection lens system according to still another aspect of the present invention includes: a first lens having a weak refractive power; a second lens having a weak refractive power; a third lens having a strong positive refractive power; a fourth lens for correcting an aberration being in lights from the third lens; and a fifth lens having a negative refractive power; and at least one diffractive optical element formed on at least one among the surfaces of the lenses.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects of the invention will be apparent from the following detailed description of the embodiments of the present invention with reference to the accompanying drawings, in which:

Fig. 1A and Fig. 1B are a front view and a side view of a conventional rear projection device, respectively;

Fig. 2 is a detailed view of the conventional projection lens system;

Fig. 3 is a detailed view of a projection lens system according to an embodiment of the present invention;

Fig. 4 is a view of a light path explaining a diffractive

characteristic of light by a lens designed with a diffractive optical element adapted to the present invention;

Fig. 5 is a view showing a converging state of lights by first diffractive lights when a diffractive optical element is adapted to a flat surface;

Fig. 6 is a detailed view of a projection lens system according to another embodiment of the present invention;

Fig. 7A and Fig. 7B illustrate a dispersion characteristic of a refracting lens and a diffractive optical element to a light beam, respectively;

Fig. 8 is a graph showing a relationship of a phase amount to the diffractive surface of the diffractive optical element.

Fig. 9A and 9B are graphs showing a chromatic aberration correction characteristic of the projection lens system according to an embodiment of the present invention; and

Fig. 10 is a detailed view of a projection lens system according to still another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 3 shows a projection lens system according to an embodiment of the present invention. The projection lens system of Fig. 3 includes three lenses 30, 32 and 34. A side surface of the first lens 30 is designed a surface having a diffractive optical function, thereby enhancing a performance of lens system and allowing a mechanism to be small in size. To this end, the projection lens system of Fig. 3 includes the first lens 30 having a diffractive

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optical surface; the second lens 32 for refracting lights passed through the first lens 30; and the third lens 34 for correcting a field curvature and an astigmatism of the lights passed through the second lens. The front surface S1 of the first lens 30 is formed in aspheric surface and the rear surface S2 of the first lens 30 is formed to have a diffractive optical element 30A thereon. The first lens 30 corrects a spherical aberration of optical system. In this case, the diffractive optical surface S2 is very effective relative to the other lenses having a substantially equal dispersion characteristic because of having a negative dispersion characteristic, in the correction of axial chromatic aberration. Also, the diffractive optical surface S2 is fabricated by a plastic molding process such that a mass-productivity enhances and a manufacturing cost decreases. The second lens 32 has very strong refractive power because of being a spherical glass lens. Since the second lens 32 is insensible to the temperature variation, the second lens 32 can assure a stable performance against the variation of external temperature. The third lens 34 is formed in a concave shape and installed to a coolant 36 on the front surface of cathode ray tube panel 38. The third lens 34 corrects a field curvature and distortion aberrations.

The diffractive optical surface S2 employed to the projection lens system is formed in a fine structure of micron size, as shown in Fig. 4. The diffractive optical surface S2 shown in Fig. 4 makes to diffract instead of to refract lights refracted at which the lights have passed through the front surface S1 of the first lens 30. In this

case, the diffractive lights is separated into 0th order diffractive lights (m=0), first order diffractive lights (m=±1), second order diffractive lights (m=±2), and higher order diffractive lights above third order by the characteristic of the diffractive optical element 30A. If the pitch, the structure and the depth of the diffractive optical element 30A are adjusted, the diffractive lights of desirable order can be obtained. Such a characteristic of diffractive optical element 30A' is employed, the refractive lens can obtain a substantially high refractive index by only a shape of lattice regardless to a refractive index of material, a curvature of lens and a thickness determining the refractive power. Also, if it is appropriately adjusted a phase term of the diffractive optical element 30A, which has many coefficients, as an aspherical surface, the aberration is effectively corrected.

Also, a desired refractive power can be obtained when the diffractive optical element 30A is formed on one surface of the flat panel 35 as shown in Fig. 5. The diffractive optical element 30A formed on the flat panel 35 has a positive refractive power in spite of the flat surface. This results from that the diffractive optical element 30A is designed to provide with the 1st order diffractive lights and to eliminate the high order diffractive lights. To this end, the refractive lens employing the diffractive optical element can obtain a desirable refractive power by only the flat surface without the curvature for providing a negative or a positive refractive power to the refractive lens. Such a characteristic of the diffractive

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optical element 30A forces the thickness and size of the lens system to be small.

Table 1 represents first data regarding the radius r of each lens surface, distances d between the lenses, the refractive power Nd and Abbe's number ν_d of each lens. Tables 2 and 3 represent first coefficient values defining a shape of aspherics and diffractive optical element 30A, respectively.

Table 1

Lens	Surface	r	d	Nd	ν_d
First	S1	65.841	6.930	1.4915	57.8
Lens	S2	200.000	30.437		
Second	S3	98.102	20.000	1.5943	62.0
Lens	S4	-92.729	35.026		
Third	S5	-54.000	3.500	1.5090	51.9
Lens	S6	-50.000	9.000	1.4395	62.8
CRT	S7	Flat	14.100	1.5632	55.2
Panel	S8	-350.000			

Table 2

	K	A	B	C	D	E
S1	-0.1597	-0.5007E -09	-0.4273E -07	0.4141E -12	-0.3524E -15	0. 6939E -19
S2	-3.2887	-0.1541E -04	0. 2379E -07	-0.3023E -10	0. 1776E -13	-.3834E -17

Table 3

	HZ1	HZ2	HWL	C1	C2	C3
S2	-0.1000E 3	-0.1100E 3	544.00	4.1763 -05	9.9045E -08	7.7178E -11

Table 4 represents first data regarding the radius r of
each lens surface, distances d between the lenses, the
refractive power Nd and Abbe's number ν_d of each lens.
Tables 5 and 6 represent first coefficient values defining
a shape of aspherics and diffractive optical element 30A,
respectively.

Table 4

Lens	Surface	r	d	Nd	ν_d
First Lens	S1	65.841	6.930	1.4915	57.8
	S2	200.000	30.437		
Second Lens	S3	98.102	20.000	1.5943	62.0
	S4	-92.729	35.026		
Third Lens	S5	-54.000	3.500	1.5090	51.9
	S6	-50.000	9.000	1.4395	62.8
CRT Panel	S7	Flat	14.100	1.5632	55.2
	S8	-350.000			

Table 5

	K	A	B	C	D	E
S1	-0.0656	-0.5107E -06	-0.2450E -09	0.2173E -12	-0.1598E -15	0.2394E -19
S2	-0.9022	-0.1121E -04	0.2084E -07	-0.3039E -10	0.2062E -13	-.5216E -17

Table 6

	HZ1	HZ2	HWL	C1	C2	C3
S2	-0.1000E -13	-0.1100E -03	544.00	-1767E -05	6.0183E -08	7.2765E -17

The data represented in tables 1 to 6 have meanings as
follows. Firstly, the aspheric coefficients defining a
shape of surfaces S1 and S2 of aspherics 30 are determined

by the following equation:

$$X(r) = [cr^2/\{1+(1-(1+K)c^2r^2)\}^{1/2}] + Ar^4 + Br^6 + Cr^8 + Dr^{10} + Er^{12} \cdots \quad -- (2)$$

5 Wherein, $X(r)$ is a sag value of with reference to a aspheric surface at a height r from an optical axis, c does a curvature of the lens surface at the height r from an optical axis, K does a conic constant, and A to E do aspheric coefficients.

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"HZ1" and "HZ2" in tables 3 and 6 are distances from the diffractive optical element 30A to an object point source and to a reference point source. Since the diffractive optical element 30A applied to the projection lens system

15 of the present invention has a spindle symmetrical characteristic, the object and reference point sources are positioned at an optical axis. "HWL" is a reference wave length of light beam which is used to the fabrication of the diffractive optical element 30A. The present

20 invention uses a light beam from a green cathode ray tube, which has the center wave length of 544nm, as the reference wave length. A aspheric phase amount of the diffractive optical element, which is generated by an interference of lights from an object source and a

25 reference source, is determined by the following equation:

$$\varphi(y) = c_1 y^2 + c_2 y^4 + c_3 y^6 + \cdots \quad ------------------ (3)$$

wherein $\varphi(r)$ represents a phase at a position

30 corresponding to the height of y from the optical axis, and c_1 to c_3 to E represent coefficients of the phase item

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having a aspheric effect. F/# of the projection lens system, which the first data and coefficient values represented in tables 1 to 3 are applied to, is 1.047. Then, a focal length is 74.0 mm. Also, F/# of the projection lens system, which the second data and coefficient values represented in tables 4 to 6 are applied to, is 1.054. Then, a focal length is 78.2449 mm. In the projection lens system of Fig. 3, which the data described above is adaptable to, facilitates a combination and adjustment thereof because all of the aspherics 30 and the diffractive optical element 30A has the spindle symmetrical characteristic against the optical axis.

Referring to Fig. 6, there is shown a projection lens system according to an embodiment of the present invention. The projection lens system includes a first lens 20 having a positive refractive power at the center thereof and having a negative refractive power at the peripheral thereof, a second lens 22 having a positive refractive power, a third lens 24 having a positive refractive power and provided with a diffractive optical element (DOE) at one side thereof, and a fourth lens 26 having a negative refractive power. The first lens 20 consists of a aspheric lens made from a plastic material to correct a spherical aberration. Also, the first lens 20 has a positive refractive power at the center thereof and a negative refractive power at the peripheral thereof to correct a comma aberration and an astigmatism. The second lens 22 is made from a glass material and is responsible for the majority of entire refractive power in the projection lens system. The third and fourth lenses 24 and 26 consist of a

plastic lens to correct an astigmatism and field curvature.
The third lens 34 has a structure in which a diffractive
optical element 24A is formed at one side of the lens with
a positive refractive power so as to correct a color

5 aberration.

In detail, conventional refractive lens 28 enables a focal
length of blue light beam to be shorter than that of red
light beam, among the light beams having color signals as

10 shown in Fig. 7A. Meanwhile, the diffractive optical
element 24A forces a focusing distance of red light beam
to be shorter than that of blue light beam, among the
light beams having color signals as shown in Fig. 7B. In
this case, the Abbe's number ud representing the

15 dispersion of refractive lens 28 is determined by
following equation:

$$\nu_d = (N_d - 1) \,/\, (N_F - N_c) \quad\text{------------------------} \quad (4)$$

20 Wherein, "N" is a refractive index at a spectrum wave
length of each added letter. Also, when a wave length of
spectrum ray for each added letter is "λ", Abbe's number
of diffractive optical element 24A is determined by
following equation:

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$$\nu_d = \lambda_d \,/\, (\lambda_F - \lambda_c) = -3.45 \quad\text{------------------} \quad (5)$$

As seen in equations 4 and 5, Abbe's number ud of the
refractive lens 28 has the positive value of about 25 to
65, while Abbe's number of the diffractive optical element

30 30A the negative value of −3.45. In other words, the
refractive lens 28 and the diffractive optical element 30A

have the chromatic dispersion characterists opposite to each other. To this end, the third lens 24 including a plastic lens (i.e., a refractive lens) having a positive refractive power and the diffractive optical element 24A having the diffractive characteristic and being formed on the surface of the plastic lens corrects by using the oppsosite chromatic dispersion characteristics. The projection lens system shown in Fig. 6 has a good chromatic aberration correction characteristic by the third lens 24, as shown in Fig. 9A and 9B. In Figs. 9A and 9B, "PR", "PG" and "PB" are light characteristic by the present invention, and "OR", "OG" and "OB" are light characteristic by the prior art. As seen in a chromatic aberration graph varying along with the height y from the optical axis on the Y axis shown in Fig. 9A and a chromatic aberration graph in accordance with the height y from the optical axis on the X axis shown in Fig. 9B, the third lens 24 forces the chromatic aberrations for the red, green and blue to decrease, thereby enhancing the chromatic aberration correction characteristic.

Table 7 represents data regarding the radius of curvature r of each lens surface, distances d between the lenses, the refractive power N_d and abbe's number ν_d of each lens, which is adaptable to the projection lens system shown in Fig. 6. Tables 8 represents coefficient values defining a shape of asperics and diffractive optical element 30A as shown in Fig. 6.

Table 7

LENS	S	r	d	N_d	ν_d
1ST LENS	S11	72.4300	8.6400	1.4935	57.8
	S12	80.9700	28.8000		
2ND LENS	S13	73.6700	25.0000	1.5916	62.0
	S14	-215.3300	20.0200		
3RD LENS	S15	-359.8100	8.0000	1.4938	57.8
	S16	-94.5	29.55		
4TH LENS	S17	-49.5100	3.5000	1.4938	57.8
	S18	-47.0000	12.9400	1.4392	62.8
CRT	S19	Infinity	14.1000	1.5551	55.2
PANEL	S20	-350.0000	0.000		

TABLE 8

LENS SURFACE	K	A	B	C	D	E
S11	-1.3480E+00	1.6080E-07	-8.4679E-10	1.5770E-13	1.3850E-17	-2.9262E-21
S12	5.0000E-02	5.3046E-07	-1.8278E-09	1.4642E-12	-7.9311E-16	2.5535E-19
S15	8.3325E+01	-1.5942E-06	-6.9339E-10	3.800E-13	-6.0061E-16	2.0398E-19
S16	-14.987	9.66E-07	5.32E-10	-3.77E-13	-3.26E-17	0
S17	0.432533	-3.12E-06	1.09E-08	-1.90E-11	1.80E-14	-8.65E-18
S16(DOE)	0	-4.45E-04	0	0	0	0

In Table 8, the coefficient values determining the shape
of the first lens 20 formed in a aspheric surface and the
shapes of the third and fourth lenses 24 and 26 are
defined by the equation 2 as described above. Also, a
aspheric phase amount of the diffractive optical element
24A generated by an interference between a object source
and a reference source in the diffractive optical element
24A is determined by the phase amount equation 3 described
above. The phase amount of the diffractive optical
element 24A applicable to the present invention has a
characteristic reduced in proportion to the height r from

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the optical axis as shown in Fig. 8. The phase amount characteristic graph of the diffractive optical element 24A shown in Fig. 8 is related to a zone number of the diffractive optical element 24A, and which shows a requirement for an optimum design of the phase amount for which the diffractive optical element 24A for the purpose of improving an optical performance in consideration of a diffraction efficiency and a working performance of lens. To this end, the diffractive optical element 24A is formed in such a manner that a plurality of recesses with a concentric circles shape has a rotational symmetry, and a pitch of the recess becomes smaller as it goes from the center into the peripheral. A chromatic aberration, a spherical aberration and a distortion aberration, etc. can be corrected by combining such a diffractive optical element 24A with the aspheric plastic lens.) Accordingly, it is not required to additionally use lenses of an expensive material having a negative refractive power and enlarging a dispersion of beam like the prior art so as to correct a color aberration, so that the present invention is capable of reducing a manufacturing cost and is advantageous in making a small-size projection lens system. Also, the projection lens system can be made into a thinner type as a focus length of the projection lens system becomes shorter. To this end, it is desirable that the second lens 22 responsible for the majority of the entire refractive power is designed to have a large refractive power. When the refractive power is large, however, a spherical aberration is generated to thereby have a limit in enlarging a refractive power of the second lens 22. Accordingly, a refractive power of the second

lens 22 is distributed to the diffractive optical element 24A to raise a refractive power of the projection lens system and thus reduce the entire focal length, so that a thin-type device can be made.

Furthermore, a brightness of the projection lens system can be improved with the aid of the diffractive optical element 24A. In other words, a refractive power is distributed to the diffractive optical element 24A to reduce a focal length of the projection lens system, so that a brightness of the projection lens system can be improved. This is because a brightness of the projection lens system is in inverse proportion to a square of F/# having a relationship proportional to a focus length f as indicated in the following equation:

$$\text{Brightness} \propto 1 \,/\, (F/\#)^2, \quad F/\# = f/D \quad \text{---------} \quad (3)$$

wherein D represents a diameter of the lens. Since F/# becomes smaller as the entire focal length of the projection lens system is smaller as seen from said equation (6), a brightness of the projection lens system being in inverse proportional to a square of F/# becomes better so that a high brightness can be realized.

As described above, the present projection lens system employs the diffractive optical element 24A to correct a color aberration and a spherical aberration, etc., thereby improving an optical performance without increasing the number of lenses. Also, the present projection lens system employs the diffractive optical element 24A to undertake

partial responsibility for a refractive power and thus reduce the entire focal length, so that a thin-type device and a high brightness can be obtained. In addition, the present projection lens system takes advantage of the first lens 20 having a aspheric surface and having a positive refractive power at the center thereof and a negative refractive power at the peripheral thereof to compensate for optical aberrations (i.e., a spherical aberration, a waveform aberration and an astigmatism), thereby reducing the number of lenses.

Fig. 10 shows a projection lens system according to an embodiment of the present invention. The projection lens system of Fig. 10 includes a first lens 110 having a positive refractive power, a second lens 120 having a weak refractive power, a third lens 130 having a positive refractive power, a fourth lens 140 having a diffractive optical element (DOE) 140a formed on one side thereof, and a fifth lens 90 having a negative refractive power. The first and second lenses 110 and 120 consist of an aspheric lens made from a plastic material to correct a spherical aberration. The third lens 130 is made from a glass material and is responsible for the majority of entire refractive power in the projection lens system. The fourth and fifth lenses 140 and 150 consist of a plastic lens to correct an astigmatism and field curvature. The fourth lens 140 has a structure in which a diffractive optical element 140a is formed at one side of the lens with a positive refractive power so as to correct a chromatic aberration. The fourth lens 140 has a good chromatic aberration correction characteristic as the refractive

lens and the diffractive optical element 140A have the
chromatic dispersion characteristics opposite to each
other. The projection lens system has the good chromatic
aberration correction characteristic by the fourth lens
5   140, as shown in Figs. 9A and 9B.

The aspheric phase amount varying along with the height y
from the optical axis and defining a surface shape of the
diffractive optical element 140A is determined by the
10   phase amount equation 3 described above. The phase amount
of the diffractive optical element 140A applicable to the
present invention has a characteristic reduced in
proportion to the height y from the optical axis as shown
in Fig. 8. The phase amount characteristic graph of the
15   diffractive optical element 140A shown in Fig. 8 is
related to a zone number of the diffractive optical
element 24A, and which shows a requirement for an optimum
design of the phase amount for which the diffractive
optical element 140A for the purpose of improving an
20   optical performance in consideration of a diffraction
efficiency and a working performance of lens. To this end,
the diffractive optical element 140A is formed in such a
manner that a plurality of recesses with a concentric
circles shape has a rotational symmetry, and a pitch of
25   the recess becomes smaller as it goes from the center into
the peripheral. A chromatic aberration, a spherical
aberration and a distortion aberration, etc. can be
corrected by combining such a diffractive optical element
24A with the plastic aspheric lens. Accordingly, it is not
30   required to additionally use lenses of an expensive
material having a negative refractive power and enlarging

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a dispersion of beam like the prior art so as to correct a color aberration, so that the present invention is capable of reducing a manufacturing cost and is advantageous in making a small-size projection lens system. Also, the projection lens system can be made into a thinner type as a focal length of the projection lens system becomes shorter. To this end, it is desirable that the third lens 130 responsible for the majority of the entire refractive power is designed to have a large refractive power. When the refractive power is large, however, a spherical aberration is generated to thereby have a limit in enlarging a refractive power of the third lens 130. Accordingly, a refractive power of the third lens 130 is distributed to the diffractive optical element 140A to raise a refractive power of the projection lens system and thus reduce the entire focus length, so that a thin-type device can be made. Also, a refractive power is distributed to the diffractive optical element 24A to reduce a focus length of the projection lens system, so that a brightness of the projection lens system can be improved. This is because a brightness of the projection lens system is in inverse proportion to a square of F/# having a relationship proportional to a focal length f, as the equation (6) described above.

Table 9 represents first data regarding the radius r of each lens surface, distances d between the lenses, the refractive power N_d and abbe's number ν_d of each lens, which is adaptable to the projection lens system shown in Fig. 10. Tables 10 represents first coefficient values defining a shape of aspherics 110, 120, 140 and 150 and a

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surface shape of diffractive optical element 140A as shown in Fig. 10. In table 10, the first coefficient values defining a shape of the aspheric surface in the first, second, fourth and fifth lenses 110, 120, 140 and 150

5 are determined by the equation (2) as described above.

Table 9

LENS	LENS SURFACE	r	d	N_d	ν_d
1ST LENS	S21	111.000	8.600	1.494000	57.8
	S22	299.109	14.400		
2ND LENS	S23	-140.000	8.200	1.494000	57.8
	S24	-155.321	3.600		
3RD LENS	S25	74.500	25.000	1.592000	62.0
	S26	-220.500	9.863		
4TH LENS	S27	-415.000	7.000	1.494000	57.8
	S28	-115.876	33.000		
5TH LENS	S29	-50.782	3.500	1.494000	57.8
	S30	-45.000	9.000	1.430000	62.8
CRT	S31	Infinity	14.1	1.563000	55.2
PANEL	S32	-350.0	0		

TABLE 10

LENS SURFACE	K	A	B	C	D	E
S21	-17.15900	1.162E-07	-1.313E-09	-4.585E-13	4.961E-16	-1.025E-19
S22	0.000000	6.029E-07	7.796E-10	-5.599E-13	4.406E-16	-8.283-20
S23	-10.000000	1.717E-06	-2.944E-10	-1.286E-12	4.009E-16	0.000E+00
S24	-1.727000	1.612E-06	-3.750E-10	-1.096E-12	5.164E-16	-5.476E-20
S27	101.81000	5.163E-07	3.253E-10	-1.839E-14	4.097E-16	0.000E+00
S27(DOE)	0.000000	-2.546E-04	0.000000	0.000000	0.000000	0.000E+00
S28	-41.46900	2.136E-06	3.747E-09	-3.142E-12	1.889E-15	-2.799E-19
S29	-0.77700	5.140E-06	2.687E-09	-3.730E-12	2.504E-15	-7.896E-19
S30	0.000000	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

On the basis of the data represented in tables 9 and 10, the shape of each lens included in the projection lens system according to embodiment of the present invention is decided and designed. Also, there will be described a treating method of the aspheric lens. Actually, the front face of the first lens 110 having the radius of 111.000 is formed by which A to E positions on the spherical lens having a constant radius are treated to correspond to the coefficients in table 10. The first, second, fourth and fifth lenses 110, 120, 140 and 150 are formed by the same treating process.

Table 11 represents second data regarding the radius of r of each lens surface, distances d between the lenses, the refractive power N_d and abbe's number ν_d of each lens, which is adaptable to the projection lens system shown in Fig. 10. Tables 12 represents second coefficient values defining a shape of asphelics 110, 120, 140 and 150 and a surface shape of diffractive optical element 140A as shown in Fig. 10.

Table 11

LENS	LENS SURFACE	r	D	N_d	ν_d
1ST LENS	S21	101.635	8.600	1.494000	57.8
	S22	190.658	15.400		
2ND LENS	S23	280.338	8.200	1.494000	57.8
	S24	443.295	3.600		
3RD LENS	S25	78.280	25.000	1.592000	62.0
	S26	-194.639	7.000		
4TH LENS	S27	-712.755	7.000	1.494000	57.8

	S28	-137.901	33.562		
5TH LENS	S29	-48.084	3.500	1.494000	57.8
	S30	-45.000	9.000	1.430000	62.8
CRT	S31	Infinity	14.1	1.563000	55.2
PANEL	S32	-350.0	0		

TABLE 12

LENS SURFACE	K	A	B	C	D	E
S21	-10.000000	2.963E-07	-1.925E-09	1.485E-14	3.251E-16	-6.104E-20
S22	0.0000000	5.029E-7	-2.422E-09	6.559E-13	4.874E-17	-1.649E-20
S23	-10.0000000	1.717E-06	-2.944E-10	-1.288E-12	4.009E-16	0.000E+00
S24	0.000000	9.716E-07	1.142E-10	-1.612E-12	6.936E-16	-7.465E-20
S27	24.65800	2.926E-07	-3.045E-11	5.413E-14	2.714E-16	0.000E+00
S27(DOE)	0.000000	-2.000E-04	0.000000	0.000000	0.000000	0.000000
S28	-45.04800	1.117E-06	1.429E-09	-6.531E-13	4.908E-16	-1.380E-20
S29	0.000000	5.236E-06	3.978E-09	-4.788E-12	3.183E-15	-9.871E-19
S30	0.000000	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

On the basis of the data represented in tables 11 and 12, the shape of each lens included in the projection lens system according to embodiment of the present invention is decided and designed. Also, there will be described a treating method of the aspheric. Actually, the front face of the first lens 110 having the radius of 101.635 is formed by which A to E positions on the spherical lens having a constant radius are treated to correspond to the coefficients in table 12. The first, second, fourth and fifth lenses 110, 120, 140 and 150 are formed by the same treating process.

Table 13 represents third data regarding the radius of curvature r of each lens surface, distances d between the lenses, the refractive power N_d and abbe's number ν_d of

each lens, which is adaptable to the projection lens system shown in Fig. 10. Tables 14 represents third coefficient values defining a shape of aspherics 110, 120, 140 and 150 and a surface shape of diffractive optical
5   element 140A as shown in Fig. 10.

Table 13

LENS	LENS SURFACE	r	d	Nd	ν_d
1ST LENS	S21	82.962	8.600	1.494000	57.8
	S22	121.163	15.381		
2ND LENS	S23	280.338	8.200	1.494000	57.8
	S24	817.986	3.660		
3RD LENS	S25	71.753	25.000	1.592000	62.0
	S26	-265.639	7.020		
4TH LENS	S27	-356.111	7.000	1.494000	57.8
	S28	-127.715	33.000		
5TH LENS	S29	-52.782	3.500	1.494000	57.8
	S30	-45.000	9.000	1.430000	62.8
CRT	S31	Infinity	14.1	1.563000	55.2
PANEL	S32	-350.0	0		

TABLE 14

LENS SURFACE	K	A	B	C	D	E
S21	-10.525000	1.446E-06	-2.585E-09	-2.577E-13	6.292E-16	-1.224E-19
S22	0.000000	5.697E-07	-2.303E-09	-1.592E-13	5.906E-16	-1.153E-19
S23	-10.000000	1.717E-06	-3.481E-10	-1.286E-12	4.009E-16	0.000E+00
S24	0.000000	7.759E-07	-3.480E-10	-9.128E-13	2.923E-16	0.000E+00
S27	-85.58500	3.547E-07	-1.366E-09	2.086E-12	4.252E-16	0.000E+00
S27(DOE)	0.000000	-2.546E-04	0.000000	0.000000	0.000000	0.000000
S28	-45.04800	1.599E-06	1.098E-09	4.231E-13	1.535E-16	0.000E+00
S29	0.000000	6.856E-06	8.342E-09	-1.223E-11	8.706E-15	-2.530E-18
S30	0.000000	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

On the basis of the data represented in tables 13 and 14, the shape of each lens included in the projection lens system according to embodiment of the present invention is decided and designed. Also, there will be described a treating method of the aspheric lens. Actually, the front face of the first lens 110 having the radius of 82.962 is formed by which A to E positions on the spherical lens having a constant radius curvature are treated to correspond to the coefficients in table 14. The first, second, fourth and fifth lenses 110, 120, 140 and 150 are formed by the same treating process.

As described above, the projection lens system according to the present invention employs a diffractive optical element to correct a color aberration and a spherical aberration, etc., so that it is capable of implementing a high resolution without adding the lenses of flint series as well as reducing the manufacturing cost. Also, the projection lens system according to the present invention employs a diffractive optical element to reduce a focal length, so that a thin-type device and a high brightness can be obtained.

Although the present invention has been explained by the embodiments shown in the drawings described above, it should be understood to the ordinary skilled person in the art that the invention is not limited to the embodiments, but rather that various changes or modifications thereof are possible without departing from the spirit of the invention. Accordingly, the scope of the invention shall

be determined only by the appended claims and their equivalents.